BP 38: Active Matter VI (joint session DY/BP)

Time: Friday 9:30–12:15 Location: ZEU/0160

Invited Talk BP 38.1 Fri 9:30 ZEU/0160

Morphogenesis, transport, and computation in micro-scale swarms — •Akira Kakugo — Division of Physics and Astronomy, Graduate School of Science, Kyoto University, Kyoto, Japan

Collective behavior at the microscale offers a powerful route to creating adaptive and functional materials. In this talk, I present a series of studies in which microtubule/kinesin active matter is treated as an ensemble of active agents, and swarming is engineered through DNA-mediated interactions. By introducing programmable dipole-dipole like binding via designed DNA motifs, we establish tunable microscale swarms with controllable cohesion. First, I describe how external mechanical stimuli trigger diverse modes of morphogenesis within these swarms, leading to the emergence of ordered structures and pattern transformations. Next, I introduce a DNA-programmable transport system in which a swarm of millions of active agents cooperatively captures, carries, and releases microscale cargo, enabling light-controlled, spatiotemporally precise transport. Finally, I demonstrate how such active swarms can function as a physical reservoir, where their high-dimensional, nonlinear dynamics are directly harnessed for computation within an active-matter ensemble.

BP 38.2 Fri 10:00 ZEU/0160

Learning effective hydro-phoretic interactions in active matter — •Palash Bera, Aritra K. Mukhopadhyay, and Benno Liebchen — Technische Universität Darmstadt, Darmstadt, Germany.

In the quest to understand collective behaviors in active matter systems, the complexity of hydrodynamic and phoretic interactions remains a fundamental challenge. Despite the substantial progress in identifying effective models, existing approaches often rely on minimalistic approximations, neglecting many-body interactions and the near-field contributions to the full interaction dynamics. We propose a machine learning-based framework to systematically learn hydrophoretic interactions among active colloids from first principles. By combining high-fidelity simulations with symmetry-preserving descriptors and neural network architectures, our approach captures the effective representations of both near- and far-field interactions. This framework bridges the gap between microscopic continuum models and coarse-grained active matter simulations, enabling scalable many-particle modeling without explicitly resolving the fluid flow or concentration fields. Built on two-body interactions, the coarse-grained model captures clustering phenomena consistent with those observed experimentally in active matter systems. We envision that the principles and tools developed here will have broad applicability across a wide range of active and nonequilibrium systems, including driven colloids, active gels, and field-responsive materials, providing a robust framework for modeling emergent behaviors in living and life-like systems.

BP 38.3 Fri 10:15 ZEU/0160

Interactions between Janus particles in optical tweezers — •Arnaud Compagnie[1], Abhimanyu Nowbagh[2], Ivo Buttinoni[2], and Hartmut Löwen[1] — [1]Institute for Theoretical Physics II, Heinrich Heine University Düsseldorf, 40225 Düsseldorf, Germany — [2]Institute for Experimental Physics of Condensed Matter, Heinrich Heine University Düsseldorf, 40225 Düsseldorf, Germany

Janus particles, by using their asymmetric properties to self-propel due to phoretic effects, are the most prominent artificial active colloids at the microscale. Their ability to extract energy from their surroundings and to self-assemble are used to perform specific tasks. However, due to the vast amount of types of Janus particles and the complex systems they evolve in, the way they interact with their environment remains poorly understood. Optical tweezers can be used to trap them and control their behaviour. By studying how a trapped Janus particle affects the movements of another one in a separate trap, we aim to identify the main physical phenomena - optics, hydrodynamic fluxes, and phoretic fields - that influence the interactions between them. We establish and simulate physical models in order to derive the characteristic dynamical properties of the Janus particles thanks to the comparison with experimental data.

BP 38.4 Fri 10:30 ZEU/0160

Programmable Hydrodynamic Reconfiguration of Active Particles — •Lisa Rohde, Gordei Anchutkin, and Frank Cichos — Molecular Nanophotonics Group, Peter-Debye-Institute for Soft Matter Physics, University Leipzig, Leipzig, Germany

Self-propelled microparticles generate hydrodynamic flow fields that govern their interactions with boundaries and neighbouring particles. The long-range behavior of the flow patterns classifies them as either pushers, pullers or neutral swimmers - each exhibiting fundamentally different collective behaviours. In nature, some microorganisms can adaptively switch between swimming modes in response to their environment. However, in synthetic matter, the hydrodynamic signature is fixed during fabrication constraining our ability to study how switching between modes might enable new emergent behavior. Here, we demonstrate a novel approach for real-time switching of the hydrodynamic character of the microswimmer. By illuminating the particle with a structured light field, we create tailored temperature gradients that drive controllable slip flows on the particle*s surface. This effectively allows control over the swimmer*s flow field and enables mode switching by dynamically changing the illumination pattern on demand. The ability to alter the propulsion characteristics established a versatile platform for experimentally investigating swimming efficiency, adaptivity, and collective behavior.

BP 38.5 Fri 10:45 ZEU/0160

From Passive to Active: Active Particles in Coatings Formulation and Film Formation — •Jan Cammann[1], Karnika Singh[1], Luka Burduli[1,2], Edgar Espinosa Rodriguez[3], Franck D'Agosto[3], Muriel Lansalot[3], and Ignacio Martin-Fabiani[1] — [1]Loughborough University — [2]Constructor University Bremen — [3]Universite Claude Bernard Lyon

Coatings are widely used in protective and functional applications but are fundamentally limited by the passive nature of their formulation ingredients. This leads to a critical lack of control over the spatial distribution of ingredients and prevents the optimization of key functional properties. Addressing this challenge, we propose a paradigm shift towards active coatings formulation. We introduce active Janus particles in coatings formulations and demonstrate how they overcome sedimentation and chemical gradients to accumulate at both the top and bottom coating interfaces. To achieve this programmable microstructure, we balance the timescales of active particle fuel depletion and evaporation induced assembly. We find that Janus particles at the top coating surface have an orientational bias, with the sub-equatorial orientation being the most common. This work lays the foundation for future studies developing functional coatings with programmable microstructures and dual functionalities enabled by orientation-biased active particles.

15 min. break

BP 38.6 Fri 11:15 ZEU/0160

Critical Dynamics of Active, Isotropic Systems — •Emir Sezik and Gunnar Pruessner — Imperial College London

A central result of field theory and renormalisation group (RG) is the concept of universality classes. Systems with different microscopic properties display the same physics near a continuous phase transition as they share the same symmetries. In equilibrium critical dynamics, where systems relax to a thermal steady state, Hohenberg and Halperin have provided the authoritative catalogue, which however, does not immediately extend to critical active matter systems. As they display exciting and new phases by their breaking of detailed balance, we have every reason to attempt to identify the relevant terms and to catalogue these non-equilibrium, critical systems. Motivated by this, in this work, we study an active version of Model A by including the relevant terms that are allowed by symmetry in the coarse-grained description. We show that this universality class encompasses diverse systems including spins with vision-cone interactions and Malthusian flocks. Finally, using field-theoretic RG, we perform a 1-loop calculation, approaching the critical point from the disordered regime, and elucidate the effects of activity on the Wilson-Fisher fixed point.

BP 38.7 Fri 11:30 ZEU/0160

Conservation laws and slow dynamics determine the universality class of interfaces in active matter — •Raphael Maire[1], Andrea Plati[1], Leonardo Galliano[2,3], Frank Smallenburg[1],

Ludovic Berthier[2], and Giuseppe Foffi[1] — [1]Université Paris-Saclay, Laboratoire de Physique des Solides, 91405 Orsay, France — [2]Gulliver, ESPCI Paris, PSL Research University, 75005 Paris, France — [3]Dipartimento di Fisica, Università di Trieste, Strada Costiera 11, 34151, Trieste, Italy

While equilibrium interfaces display universal large-scale statistics, interfaces in phase-separated active and driven systems are predicted to belong to distinct non-equilibrium universality classes. Yet, such behavior has proven difficult to observe, with most systems exhibiting equilibrium-like fluctuations despite their strongly non-equilibrium microscopic dynamics.

We introduce an active hard-disk model that is far from equilibrium but lacks self-propulsion. Contrary to self-propelled models, it displays clear non-equilibrium interfacial scaling and allows the first observation of the $|\boldsymbol{q}|$KPZ and wet-$|\boldsymbol{q}|$KPZ universality classes while revealing a new, previously overlooked universality class arising in systems with slow crystalline or glassy dynamics. We also show that hyperuniformity in the bulk suppresses accordingly the fluctuations of the interface. These distinct classes are selected by conservation laws and slow hydrodynamic modes.

Our model can be experimentally realized in vibrated granular systems and offers a new route to study far from equilibrium interfaces.

BP 38.8 Fri 11:45 ZEU/0160

Spontaneous emergence of solitary waves in active flow networks — Rodrigo García[1], •Gonçalo Antunes[2,3], Jens Harting[2,4], Holger Stark[3], Chantal Valeriani[1], Martin Brandenbourger[5], Juan Mazo[1], Paolo Malgaretti[2], and Miguel Ruiz-García[1] — [1]Universidad Complutense de Madrid, Madrid, Spain — [2]Helmholtz-Institut Erlangen-Nürnberg für Erneuerbare Energien (IET-2), Erlangen, Germany — [3]Technische Universität Berlin, Berlin, Germany — [4]Friedrich-Alexander-Universität Erlangen-Nürnberg, Nürnberg, Germany — [5]Aix Marseille Université, Marseille, France

Flow networks like animal/plant vasculature and power distribution grids can encode, transmit, and transform information embodied in the spatial and temporal distribution of their flows. To study these emergent dynamics, we focus on a minimal yet physically grounded system which supports information transmission. The system is composed of a one-dimensional network of active units that pump fluid via phoresis and elastic units that store volume. We coarse-grain the elastohydrodynamics to an active flow network model. We show that the pressure field can develop solitary waves, resulting in the spontaneous creation and transmission of localized packets of information stored in the physical properties of the flow. We show how the shape and speed of these waves depend on the physical parameters. When the elastic units are coupled to their neighbors, a critical size emerges, below which the solitary waves have a finite lifetime.

BP 38.9 Fri 12:00 ZEU/0160

Instabilities and turbulence in extensile swimmer suspensions — •Purnima Jain[1], Navdeep Rana[3], Roberto Benzi[4,5], and Prasad Perlekar[2] — [1]Leibniz-Institut für Polymerforschung Dresden, Germany — [2]Tata Institute of Fundamental Research, Hyderabad, India — [3]Max Planck Institute for Dynamics and Self-Organization (MPIDS), Göttingen, Germany — [4]Hangzhou International Innovation Institute, Beihang University, Hangzhou, China — [5]Department of Physics and INFN, Tor Vergata University of Rome, Via della Ricerca Scientifica 1, Rome, Italy

Swimmers moving in the same direction form an ordered state of living matter. However, this ordered state is not always stable to ambient disturbances. This may lead to chaotic flows characterized by the presence of topological defects, a phenomenon known as active turbulence. The ordered state of microswimmers can be destroyed by an instability created by their swimming stresses. For slightly larger swimmers, where viscous and inertial forces are comparable, an instability due to the fluctuations in the concentration of swimmers destroys the order [1].

In this talk, I will discuss about the instabilities and turbulence in weakly inertial suspensions of extensile swimmers, where the defect turbulent state transitions to the concentration-wave turbulent state. These findings reveal new ways in which living matter may get organized in nature.

[1] P. Jain et. al., Phys. Rev. Lett. 133, 158302 (2024). [2] P. Jain et. al., Phys. Rev. Fluids 10, 114602 (2025).